

ARTIFICIAL INTELLIGENCE APPLICATIONS IN SPACE AND SDI - A SURVEY

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ABSTRACT

The purpose of this paper is to survey existing and planned Artificial Intelligence (AI) applications to show that AI applications are sufficiently advanced for 32% of all space applications and SDI (Space Defense Initiative) software to be AI-based software [3].

To best define the needs that AI can fill in space and SDI programs, this paper enumerates primary areas of research and lists generic application areas. Current and planned NASA and military space projects in AI will be reviewed. This review will be largely in the selected area of expert systems. Finally, direct applications of AI to SDI will be treated. The conclusion covers the importance of AI to space and SDI applications, and conversely, their importance to AI.

INTRODUCTION

AI covers a broad spectrum of areas of research and accordingly can find many different applications in space and SDI programs. AI includes problem solving, intelligent search strategies, natural language processing, speech recognition, robotics, knowledge and expert systems, computer vision, symbolic processing, logical reasoning, knowledge representation and understanding, and neural network systems. AI applications generally use what might better be termed knowledge rather than data, and frequently use heuristics (which guide trial-and-error searches) rather than algorithms. Some of the above areas of research may not be unique to AI, but they all come under its broad scope.

Using the principles and techniques of AI, generic application areas that have been successfully exploited or are currently under development include analysis, control, debugging, design, diagnosis, repair, instruction, training, interpretation, monitoring, planning, predicting, search techniques and synthesis.

NASA AI PROGRAMS

NASA has stepped up its emphasis on AI research. Its Ames Research Center, Mountain View, California [10] has been given the assignment of taking the lead in AI research. Ames has been directed to assure that its research supports what NASA is currently doing, and also its long-term requirements. NASA has placed a high priority on building "smart" systems for the future US/International space station.

Machine reasoning in uncertain situations, computer learning, and advanced AI architectures are major thrusts in the National Aeronautics and Space Administration's Information Sciences Division at Ames.

The Information Sciences Division at Ames has three sections and concentrates on basic research. The three sections in the division at Ames Research Center are the AI Research Branch, Intelligent Systems Technology Branch, and Systems Autonomy Demonstration Project Office.

At the Johnson Space Center, Houston, NASA concentrates on applying today's AI technology to existing systems.

This paper contains abstracts on expert systems from the publication 'Advanced Military Computing', reference [4], as well as other sources. The different expert systems range in maturity from proof of concept to operational. The author generally does not have information on the current status of the different systems.

SPACE TRANSPORTATION EXPERT SYSTEMS [4]

AIM. The Air Force Space Division in Los Angeles is proceeding with the procurement of an expert system called AIM that will plan the military space transportation systems for the period 1995 through 2010. AIM will be required to design a total "space force" including vehicle use, payload planning, and required support.

STALEX. The Shuttle Trajectory and Launch Window Expert System automates planning of space shuttle missions which carry geosynchronous communications satellites. Developed by the Houston Astronautics Division of McDonnell Douglas Technical Services Co., it performs launch window analysis and payload deployment scheduling. It is supposed to consistently choose the same solution as that of an experienced mission planner and was used for four space shuttle missions before flights were stopped due the Challenger accident in 1987. The expert system reduced planning time by 70% over previous computer tools.

ONEX. An Onboard EXpert System (ONEX) under development for the Johnson Space Center, Houston, will automate many of the navigational monitoring tasks aboard the space shuttle, particularly during routine rendezvous operations.

ESFAS. The Expert System for the Flight Analysis System (ESFAS), created for JSC, Houston, acts as a front end to their conventional software planning program, the Flight Analysis System (FAS). The FAS requires a high level of user expertise, but ESFAS makes its operation simple.

MARS. The Management Analysis Resource Scheduler (MARS), is designed to schedule the resources needed for each space shuttle mission. Resources include

manpower, computers, control rooms, simulators, and communications. equipment. It can spot potential problems in planning future missions and was built by Ford Aerospace and Communications Corp., Houston.

PEGASUS. The Prototype Expert Ground Analysis and Scheduler with User Support (PEGASUS), built by the Harris Corporation, is used at the Kennedy Space Center (KSC) to allocate limited amounts of equipment and other items among space shuttle flights.

EMPRESS. The Expert Mission Planning and Replanning Scheduling System (EMPRESS), built by the MITRE Corporation, is used at KSC to determine the time, resources, and tasks required to process payloads for the space shuttle.

VALEX. The VALidate EXpert System (VALEX) is used at JSC to validate software used for shuttle crew training. It discovers if a programmer has entered the wrong wind profile for winds common to the launch area, inaccurate launch weight, the wrong launch pad number or even launch site. Errors include recording the launch site as Florida when it is California.

RENEX. The RENdezvous EXpert System (RENEX) to automate rendezvous of space vehicles is being developed by JSC's Mission Planning and Analysis Division. It will graphically display what a system or program does and what data it uses and creates, and will be used for ground pre-mission planning, ground real-time planning and monitoring, and onboard planning and monitoring.

NAVEX. The NAVigation EXpert system is used to assist in the high-speed ground navigation of a shuttle flight during the ascent and entry portions of a flight. It involves monitoring and processing data from radar stations which are tracking the shuttle. It was developed by Inference Corp.

EXEPS. The EXpert Electrical Power System (EXEPS) is under development by NASA to aid in scheduling spacecraft electrical power loads. The Mission Planning and Analysis Division is responsible for characterizing the expected performance of the electrical power system before each flight, based on that flight's schedule of trajectory events and crew activities. This job currently takes up to two weeks to do manually. The expert system will function as an intelligent advisor and focuses on the man-machine interface and planning technology.

MISSION CONTROL SOFTWARE MONITOR. NASA uses this expert system to monitor the Mission Control Center software status. This job is currently done by the printer controller. The expert system will recognize which of the print status and error messages are important, what they mean, to whom they are important, and will report the appropriate status information.

HEAT. The Heuristic Error Analyzer for Telemetry (HEAT) looks at a compressed image

of the telemetry status, as output by the network data driver at mission control. It automatically distinguishes routine errors from those requiring human attention.

SATELLITE CONTROL AND TRACKING EXPERT SYSTEMS [4]

RIACS is taking part in joint projects to apply expert systems to aerospace problems. Four of these projects are: automatic grid generation being done for the Applied Computational Aerodynamics Branch, mission planning for the Infrared Telescope, automatic programming of space station systems for the Space Technology Branch, and evaluation of aircraft configurations for the Aeronautical Systems Branch.

AUTONOMOUS SATELLITE CONTROL. An expert system called Autonomous Satellite Control is being developed by the Space Technology Center, at Kirtland Air Force Base. The expert system is intended to allow a satellite to operate on its own for up to 30 days. The expert system, carried onboard a communications, navigation or reconnaissance satellite, will allow fine tuning of orbital parameters to maintain orbit, recharge batteries and perform other routine tasks that now require ground controllers.

TDRS CONTROL SYSTEM. This expert system is being developed by Contel-Spacecom and General Research and will aid in maintaining the orbital position of the Tracking and Data Relay Satellite used by the space shuttle, and should also be applicable to other satellites. It will be able to guide a satellite controller through a maneuver required to maintain the proper East-West orientation of the satellite. It monitors errors, manages thruster temperatures, monitors gyro performance, informs the controller of what is happening, and recommends steps to follow.

ESCAP. The Element Set Correction Assistant Prototype (ESCAP) expert system automatically updates database information after reading tracking sensors. It shows where orbiting objects actually are, compared to computer predictions of those orbits. This expert system was demonstrated to the Air Force Space Command by Ford Aerospace and Communications.

SCARES. The Spacecraft Control Anomaly Resolution Expert System (SCARES) expert system uses real-time monitoring to detect anomalies at an early stage. Then, using diagnostics, it localizes a fault to a specific unit or assembly, and a hypothesis generation and testing function analyzes faults not easily resolved by the diagnostic process and suggests recovery actions. It handles only anomalies in a satellite's attitude control. Planned extensions would monitor and diagnose the thermal, power, and payload systems.

MOPA. The Mission Operations Planning Assistant (MOPA) expert system will aid the Mission Planning Group at Goddard Space Flight Center to do mission planning for the Upper Atmospheric Research Satellite, to be launched by NASA in the early 1990s. It will help coordinate the daily activities for 10 instruments over an 18 month mission life.

ESSOC. The Expert System for Satellite Orbit Control (ESSOC) gives real-time aid to ground control operations. It provides continuous analysis of telemetry data throughout the stationkeeping operation by means of two-way real-time communication. It provides autonomous processing for satellite maneuvering operations. The system handles phase independent and phase-specific functions. When ESSOC makes a recommendation the user can choose to override it or ask for additional information before taking action.

SPACE STATION EXPERT SYSTEMS [4]

AMPASES. The Automatic Mission Planning and Scheduling Expert System (AMPASES) was developed to provide scheduling activities for NASA's space station. It can set up a 24-hour schedule in less than 30 minutes and a one-week schedule in an hour or two. Finding the "best" schedule may not be possible with the limited computing resources available, due to the large number of variables involved in managing space station missions. The expert system develops a high quality, reasonably efficient schedule based on the constraints and data provided. It can deal with seven crew members, 14 resources of various types, and three types of interactions among missions.

ECESIS, AESOP. The Environmental Control Expert System in Space (ECESIS) provides control of life-support systems on a space station. The Autonomous Electrical Subsystems Operational (AESOP) expert system monitors, diagnoses, and controls the space station electrical system. Both were developed by Boeing Aerospace Co.

SSES. The Space Station Expert System (SSES) was developed to provide on-board advice to space station operators when reconfiguring for unexpected, hazardous or resource-threatening events. It works in conjunction with a simulation of the space station operator's command module, and was developed by Lockheed Engineering and Management Services Co.

SPACE STATION HOUSEKEEPING. NASA has developed a space station expert system for housekeeping and maintenance on a 90-day mission. It creates a recurrent priority-ranked housekeeping schedule for long term space missions.

FREE-FLYER CONTROL. Engineers at Mitsubishi have built an experimental expert system for tracking and controlling any type of satellite, for checking out equipment and other systems, and for operating and controlling free-flyers.

ADEPT. The Automatic Detection of Electric Power Troubles (ADEPT) expert system integrates knowledge from three different suppliers to offer an advanced fault detection system, and is designed for two modes of operation: real time fault isolation and simulated modeling [11]. The system has been tested with a simulated space station

power module.

ROCKWELL INTERNATIONAL AI SPACE PROJECTS

EXCABL. Rockwell International has developed an expert system for automatically generating the payload bay cabling design for each mission of the space shuttle [8] [9]. This expert system, in production since 1986, requires less than one person-hour to complete a cable design, compared to 6 person-days previously.

EXMATCH. The EXpert Drawing MATCHing System (EXMATCH) is used on the shuttle program to automate the payload bay cabling installation Technical Order (TO) generation task [8]. Closely integrated with the EXCABL system, the cabling solution provided by EXCABL is automatically input to EXMATCH, and a master listing of all required payload cabling installation TO's is generated.

EXTOL. The Technical Order Listing EXpert System (EXTOL) is planned for development at Rockwell in the near future [8]. EXTOL will produce the initial Mission Equipment Cargo Support Launch Site Installation drawing. It will also use heuristics and data from previous missions to assist the user by producing a list of the best matches for mission TOs in the mission-unique category.

SAFE. Under development at Rockwell International for use on the space shuttle air revitalization system is the Safing and Failure Detection Expert (SAFE) [5], [15], [16]. It is designed to be crew-operated and uses a touch screen interface.

RB-ARD. The Rule-Based Abort Region Determinator (RB-ARD) for real-time monitoring and control, as a support system for ground personnel [17].

EXTRAJ. The Ascent Throttle Bucket Designer (EXTRAJ) is an expert system designed to optimize the shuttle throttle profile during ascent [14]. The throttle is set at full at liftoff (to minimize gravity losses), is reduced to limit dynamic loading, then returned to full as the atmospheric density falls off with altitude. The resulting thrust profile is called a "thrust bucket", and its shape influences fuel consumption.

DDES. The DDES is an expert system under development for the management of data displays in ground-based shuttle mission support [7].

ICA. The Intelligent Communicating Agents (ICA) expert system, currently under development, will help communication between distributed subsystems, and is intended for use by NASA to help provide autonomy for a manned mars mission experiment.

ETAR (ROBOTICS). The preliminary conceptual design of a new teleoperator robot manipulator system for Space Station maintenance missions has been completed at the Automation and Robotics Laboratory at Rockwell International, Downey, California [1].

The system consists of a unique pair of arms that is part of a master-slave, force-reflecting servomanipulator. This design allows greater dexterity and greater volume coverage than that available in current designs and concepts.

SDI AI APPLICATIONS

Rockwell International (RI), Downey, California, has SBI (Space Based Interceptor) contracts with the Air Force to produce a light weight prototype Kinetic Kill Vehicle (KKV), as the major defensive weapon in this nation's SDI program, and define the System Concepts and Integrated Test (SCIT) program, which includes defining the software for an operational SBI program. Previously, RI had conducted its own Independent Research and Development program to determine the extent to which AI is applicable to a space or ground-based interceptor program [2].

On the SBI program, RI is presently using an internally developed expert system called ADAES (Advanced Data Assessment Expert System) to help with the tremendous amount of data that is generated on the program. ADAES automates on-line data reduction, data assessment, and trend analysis functions for complex simulations. It allows intelligent data base management of initial conditions, initialization and control of simulation, real-time data monitoring, post-run performance analysis, multiple run comparison analysis, and provides operations and test teams with clear visibility of simulation performance.

SDI related software can be divided into two distinct classes: OPERATIONAL and NON-OPERATIONAL (SUPPORT) software [2].

Operational software is defined to be critical software which will be used before, during, and after an SDI battle or in support of space applications. It is comprised of actual flight software, some ground-based, some airborne, and some space-based. Support software is defined to include all other software (probably all ground-based) that is associated with supporting the life cycle of the operational software.

Candidate areas for applying AI to operational SDI software include battle station performance, weapon platform performance, flight control, constellation architecture design, end game, battle management, guidance, navigation & control, data processing, communications, and electrical power management. Other applications include off-line system development and management, Surveillance, Acquisition, Tracking, and Kill Assessment (SATKA), weapons fault analysis, and parameter tuning, and in battle management, command and control to make assumptions about "who's doing what to whom and why."

Support software that can be AI-based include automated code generators for the development phase, verification software for the verification phase, maintenance software for the maintenance phase, and testing and monitoring software for the

operational phase. A detailed discussion of SDI software producibility including a definition of the term 'software producibility' is contained in reference [3]. Personnel training software under the title of CBT (Computer Based Training) is also an example of support software.

Other generic SDI support software applications include expert and knowledge systems for boosters, SDI resources, laser weapons, phenomenology, sensors, threats, weapons, defense strategy, G2 (military intelligence), and suppliers. Expert systems normally capture their knowledge from experts, while knowledge systems generally get their knowledge from documented sources [6]. Applications include expert systems that perform the functions of communications, control, instruction, training, monitoring, planning, predicting, and threat-alert. Knowledge based workstations for threat analysis, threat alert, and defense strategy are also important SDI applications. Other applications include robots that perform remote maintenance, remote monitoring, and remote threat-alert. The importance of Artificial Intelligence to space defense was understood before SDI was established [13].

It is estimated that an early SDI system might have about 3.0 million lines of code (MLOC) of operational software and about 5.0 MLOC of support software [3]. Based upon the general capabilities of Knowledge-Based AI systems, it is estimated that about 45% of the lines of code for the support software and only about 10% of the lines of code for the operational software can be AI based software. This results in about 2.25 MLOC for the support AI software and about 0.3 MLOC for the operational AI software. The total SDI AI software is then 2.55 MLOC or about 32% of the total of 8 MLOC [3].

The beginning of the development of an operational SDI system, if funded, is approximately three years away and it will be about ten years (at the earliest) before a fully operational system, whether space or ground based, can be completed. This time interval clearly allows for advances in the speed of AI processors, such as LISP machines, supercomputers, parallel processors, optical computing etc., and in the maturity of expert systems and knowledge based tools for automated code generation and support of the full software development life cycle.

CONCLUSIONS

AI can and will be very important to space and SDI, and space and SDI can be very important to AI. There have been premature conclusions regarding the feasibility of software including AI software for the SDI program -- for example, David L. Parnas' essays of June 1985 [12]. It is the author's belief that several of the reasons given in Parnas' essays are not correct [3]. Furthermore, almost three years of progress have occurred since then, and a much more realistic and mature perspective is now available. For an "early-deploy" SDI system, the complexity of the operational software will be significantly less, thus allowing a normal maturation process by going in phases from an early-deploy system to a full-scale SDI system.

It is possible that the SDI program could be significantly watered down or even cancelled for entirely invalid political reasons. If this should occur, it would also be a serious blow to AI technology. The SDI program offers so many natural opportunities for the legitimate application of many different expert and knowledge systems, and accordingly, it can give AI the boost that it needs to become a mature and accepted technology. AI maturity is a significant 'spinoff' of a space station or an SDI program.

Considering both the operational and support software, a study by the author indicates that as much as 32% can be AI based. This same percentage is conservatively applied to space software. This is an opportunity for AI to mature that this nation should not let slip by. The short space allowed for this paper allows only touching upon the highlights of applying AI to space and SDI. It would require much more than this paper to do justice to this cause.

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